

TITLE OF THE INVENTION

FILM FORMING METHOD, SEMICONDUCTOR DEVICE AND
SEMICONDUCTOR DEVICE MANUFACTURING METHOD

5 BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a film forming method, a semiconductor device and a semiconductor device manufacturing method and, more particularly; a film forming method, a semiconductor device and a semiconductor device manufacturing method for ^{covering wiring with} forming an interlayer insulating film having a low dielectric constant to cover a wiring.

2. Description of the Prior Art

15 In recent years, the miniaturization and the reduction in thickness of the pattern ^{have been} are required with ^{for} the higher integration degree and the higher density of ^{as well as for} the semiconductor integrated circuit devices. In addition, ~~since the~~ higher speed of the data transfer, rate is also required.

20 Therefore, ^a the insulating film having ^a the low dielectric constant (referred to as a "low dielectric constant insulating film" hereinafter) and ^{low} the small RC delay is employed. ^{include} As such insulating film, there are the SiOF film ^s having the relative dielectric constant ^{of} 3.5 to 3.8, the porous SiO₂ film ^a having the relative dielectric constant 3.0 to 3.1, etc., for example.

However, ^{such a} [essentially the] low dielectric constant insulating film ^{takes up and passes} [is ready to contain the moisture, and is] ^{ready to pass the incoming moisture.} Therefore, if such ^a low dielectric constant insulating film is employed alone as the interlayer insulating film, [the] corrosion of the wiring and [the] increase in the leakage current ^{are} easily ^{result} [caused]. In order to prevent ^{same} [to them], ^a the barrier insulating film containing Si and N or Si and C is often interposed between the wiring and the low dielectric constant insulating film.

More particularly, in ^a [the] semiconductor device having [the] multi-layered wiring, ⁱⁿ [the] interlayer insulating film ^{including} [containing] barrier layers is formed between the upper wiring and the lower wiring. The interlayer insulating film containing barrier layers is formed by laminating ^a the barrier insulating film containing Si and N or Si and C, ^a the low dielectric constant insulating film, and ^a the barrier insulating film containing Si and N or Si and C, in sequence.

However, the insulating film containing Si and N has ^a the high relative dielectric constant. Therefore, even if such ^{an} insulating film ^{is made} of the thinner ^{and} film thickness ~~is~~ employed as the barrier insulating film, the dielectric constant of the overall interlayer insulating film is increased.

Also, the relative dielectric constant of the barrier insulating film containing Si and C is relatively

SUMMARY OF THE INVENTION

It is an object of the present invention to provide
~~a film forming method, a semiconductor device and a~~
~~semiconductor device manufacturing method, that are~~
 10 ~~capable of lowering~~ ^{to lower the} a dielectric constant of an
 interlayer insulating film as a whole and ^{to} suppressing
 a change ⁱⁿ of the dielectric constant due to moisture
 absorption, while preventing corrosion of a wiring and
 an increase in a leakage current.

15 In the film forming method according to the present invention, the silicon-containing insulating film is formed by ~~plasma~~^{converting to a plasma} ~~forming~~^{the} gas ~~[consisting of]~~^{any one} selected from ~~[a]~~^a group consisting of alkoxy compound^s having Si-H bonds and siloxane^{compounds} having Si-H bonds and ~~any one~~^{an} oxygen-containing gas selected from ~~a~~^{the} group consisting of O₂, N₂O, NO₂, CO, CO₂, and H₂O, ~~to react~~^{and reacting the plasma component}.

20 ~~According to the experiment, It~~^{has been} ~~is found that such~~^{the resulting} silicon-containing insulating film is dense, has ~~the~~^{resistance} high moisture proof, has ~~the small amount of contained~~^{a low} moisture ~~in the film~~^{content}, and ~~the~~^{has a} small relative dielectric constant.

25

Therefore, if the above silicon containing

insulating film is employed as the barrier insulating films (a lower protection layer and an upper protection layer) that constitute the interlayer insulating film interposed between the upper wiring and the lower wiring, and sandwich the low dielectric constant insulating film, the dielectric constant of the overall interlayer insulating film can be lowered while preventing the corrosion of the wiring and the increase in the leakage current.

According to the semiconductor device of the present invention, ^{includes a} the silicon-containing insulating film whose peak ~~of the~~ absorption intensity ~~of the~~ infrared rays is in a range of ^{0.3} the wave number 2270 to 2350 cm^{-1} , whose film density is in a range of 2.25 to 2.40 g/cm^3 , and whose relative dielectric constant is in a range of 3.3 to 4.3 , ^a is formed on the substrate.

~~According to the experiment of the inventors of this application,~~ ^{It has been experimentally} it is found that the silicon-containing insulating film having such characteristics has the high mechanical strength, is dense, is excellent in the water resistance, and has ^{a low} the small amount of contained moisture ^a in the film like the silicon nitride film, and has the relative dielectric constant smaller than ^{that of a} the silicon nitride film.

According to the configuration obtained by applying ^{In the manufacture of a} the silicon-containing insulating film of the present invention to the semiconductor device, the above

contact and

silicon- containing insulating film is formed to [✓] cover the wiring ~~and contact to it, otherwise the above~~ ^{or} ~~silicon-containing insulating film~~ ^a is formed as ~~the~~ ^{an} protection layer on ~~the~~ insulating film that covers the wiring.

The silicon-containing insulating film of the present invention has ^a the low dielectric constant, ~~has~~ ^{5, a low amount of} ~~the small amount of contained moisture in the film,~~ is dense, and ^{has} ~~is~~ excellent ~~in the~~ water resistance. Therefore, if ^a the silicon-containing insulating film is employed as ^a the protection layer ~~for~~ covering the wirings, etc., ~~the~~ corrosion of the wiring can be prevented by preventing ~~the incoming~~ moisture from entering the semiconductor device while reducing the parasitic capacitance between the wirings.

~~Also,~~ ^a the upper and lower wirings and the interlayer insulating film interposed between the upper and lower wirings are provided on ^a the substrate, and the interlayer insulating film is formed of the silicon-containing insulating film according to the present invention.

~~Also,~~ ^{includes,} the interlayer insulating film ~~is constructed~~ in order from the bottom ^a ~~by the~~ lower protection layer formed of the silicon-containing insulating film according to the present invention, the main insulating film, and ^{an} ~~the~~ upper protection layer formed of the silicon-containing insulating film according to the present invention.

If the main insulating film is ~~formed of the~~^a SiOF film, the silicon-containing insulating film according to the present invention can prevent the fluorine (F) ~~element~~ from diffusing to the outer peripheral portions of the silicon-containing insulating film. ~~Also, If the~~^I main insulating film is ~~formed of the~~^a porous insulating film having ~~the~~ high hygroscopicity, the silicon-containing insulating film according to the present invention can prevent the ~~incoming~~^{ingress} of ~~the~~^{prevent} moisture into the porous insulating film and thus ~~the~~ increase ⁱⁿ of the dielectric constant due to ~~the~~ moisture absorption ~~can be prevented.~~

Also, since ~~the~~^a silicon nitride film is not employed as the upper and lower protection layers ~~of~~^{on} the main insulating film ~~but~~^{and} the silicon-containing insulating film having ~~the~~^a low relative dielectric constant is employed, ~~the~~^{instead} dielectric constant of the overall interlayer insulating film can be reduced.

20 BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a side view ~~showing a configuration~~ of the plasma CVD film forming equipment employed in ~~a~~^{the} film forming method according to a first embodiment of the present invention;

25 FIG.2A to FIG.2E are sectional views showing structures of samples ~~employed to~~^{to determine} examined characteristics of a silicon-containing insulating film

that is formed by the film forming method according to the first embodiment of the present invention, and structures of comparative samples;

FIG.3A and FIG.3B are tables showing ~~examined~~
5 ~~results of a~~ film density of the insulating film that is formed by the film forming method according to ^athe second embodiment of the present invention using the sample of FIG.2A;

FIG.4 is a graph ~~showing examined results~~ of ~~a~~
10 moisture content and ~~a~~ water resistance of the silicon-containing insulating film that is formed by the film forming method according to ^{the}a second embodiment of the present invention using the sample of FIG.2A;

FIG.5A is a graph ~~showing examined results~~ of ~~an~~
15 infrared absorption intensity of the silicon-containing insulating film that is formed by the film forming method according to ^{the}a second embodiment of the present invention using the sample of FIG.2A;

FIG.5B is a graph ~~showing examined results~~ of ~~an~~
20 infrared absorption intensity of the silicon-containing insulating film that is formed by the film forming method according to ^{the}a second embodiment of the present invention using the comparative sample of FIG.2A;

FIG.6 is a graph ~~showing examined results~~ of ~~a~~
25 resistance of the silicon-containing insulating film that is formed by the film forming method according to ^{the}a second embodiment of the present invention using the

sample of FIG.2B;

FIG.7 is a graph ~~showing examined results of~~ ^{as determined by} a water resistance ~~due to~~ a pressure-cooker test of the silicon-containing insulating film that is formed by the film forming method according to ^{the} ~~a~~ second embodiment of the present invention using the sample of FIG.2B;

FIG.8 is a table showing ~~examined results of an~~ adhesiveness ^{for} of the silicon-containing insulating film that is formed by the film forming method according to the second embodiment of the present invention, to a coated insulating film using the sample of FIG.2C;

FIG.9 is a graph ~~showing examined results of~~ ^{determined} a defect generating rate due to a heat cycle using the sample of FIG.2D according to the second embodiment of the present invention;

FIG.10 is a graph ~~showing examined results of~~ ^{copper} a barrier characteristic ~~to a copper~~ of the silicon-containing insulating film that is formed by the film forming method according to the second embodiment of the present invention;

FIGS.11A and 11B are sectional views showing a semiconductor device manufacturing method according to a third embodiment of the present invention;

FIGS.12A to 12C are sectional views showing a semiconductor device manufacturing method according to a fourth embodiment of the present invention;

FIGS.13A to 13F are sectional views showing a

semiconductor device manufacturing method according to a fifth embodiment of the present invention;

FIGS.14A to 14C are sectional views showing a semiconductor device manufacturing method according to a sixth embodiment of the present invention; and

FIG.15 is a sectional view showing a semiconductor device manufacturing method according to ~~other~~ ^{another} embodiment of the present invention.

10 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will ^{now} be ~~described~~ ^{explained} with reference to the accompanying drawings hereinafter.

First Embodiment

15 ~~FIG.1 is a side view showing a configuration of the parallel-plate type plasma CVD film forming equipment 101 employed in a film forming method according to an embodiment of the present invention.~~ ^{shows}

20 ~~This plasma CVD film forming equipment 101 comprises a film forming portion 101A that is the place at which a silicon-containing insulating film is formed from a plasma gas on a substrate 20, and a film forming gas supplying portion 101B having a plurality of gas supply sources constituting the film forming gas.~~ ^{as including} ^{wherein} ^{for}

25 As shown in FIG.1, the film forming portion 101A has a chamber ^{wherein} ~~whose~~ pressure can be reduced, and ~~the~~ ^{which} ~~chamber 1~~ is connected to an exhausting device 6 via an

exhaust pipe 4. A switching valve 5 for controlling ^{the} ~~the~~ open ^{ing} and ^{closing communication} ~~the~~ close between the chamber 1, and the exhaust ~~the~~ device 6 is provided in the middle of the exhaust pipe 4. A pressure measuring means such as a vacuum gauge (not shown) for monitoring the pressure in the chamber 1 is provided ⁱⁿ ~~to~~ the chamber 1.

~~A pair of opposing~~ ^{An} upper electrode (first electrode) 2 and ^a lower electrode (second electrode) 3 are provided ^{opposing each other in} ~~to~~ the chamber 1. A high frequency power supply (RF power supply) 7 for supplying ~~a~~ high frequency power having a frequency of 13.56 MHz is connected to the upper electrode 2, while a low frequency power supply 8 for supplying a low frequency power ^{at} ~~having~~ a frequency of 380 kHz is connected to the lower electrode 3. The film forming gas is ^{converted into a plasma} ~~plasmanized~~ by supplying the power to the upper electrode 2 and the lower electrode 3 from these power supplies 7, 8. The upper electrode 2, the lower electrode 3, and the power supplies 7, 8 constitute the plasma generating means for ^{converting} ~~plasmanizing~~ the film forming gas ^{into a plasma}.

~~As the plasma generating means, there are the means for generating the plasma by the first and second electrodes 2, 3 of the parallel-plate type, the means for generating the plasma by ECR~~ ^{apparatus} ~~Electron Cyclotron Resonance~~ ^a ~~method, the means for generating the helicon plasma by irradiating the high frequency power from the antenna, etc., for example.~~ ^{an}

The upper electrode 2 is also used as a film forming gas distributor. A plurality of through holes are formed in the upper electrode 2, and ~~opening portions~~ ~~of~~ the through holes in the surface opposing ~~to~~ the lower electrode 3 serve as discharge ports ^{for} ~~(inlet ports)~~ of the film forming gas. The discharge ports of the film forming gas, etc. are connected to the film forming gas supplying portion 101B via a pipe 9a. Also, a heater (not shown) may be provided ⁱⁿ ~~to~~ the upper electrode 2, as ~~the case may be.~~ This is because, ~~If~~ the upper electrode 2 is heated at ^a ~~the~~ temperature of almost 100 °C during the film formation, particles ~~made~~ of reaction products ~~of the film forming gas~~, etc. can be prevented from sticking onto the upper electrode 2.

The lower electrode 3 is also used as a loading table for the substrate 20. A heater 12 for heating the substrate 20 on the loading table is provided ⁱⁿ ~~to~~ the lower electrode 3.

In the film forming gas supplying portion 101B, a supply source for the alkoxy compound having Si-H bonds; a supply source for the siloxane having Si-H bonds; a supply source for ^{an} ~~any one~~ oxygen-containing gas selected ^{the} ~~from a~~ group consisting of oxygen (O₂), nitrogen monoxide (N₂O), nitrogen dioxide (NO₂), carbon monoxide (CO), carbon dioxide (CO₂), and water (H₂O); a supply source for the hydrogen (H₂); and a supply source for the nitrogen (N₂) are provided.

As for the alkoxy compound having Si-H bonds or the siloxane having Si-H bonds as the film forming gas to which the present invention is applied, ^{the} followings ~~may~~ ^{are} be employed as the typical examples.

5 (i) alkoxy compound having Si-H bonds

trimethoxysilane (TMS: $\text{SiH}(\text{OCH}_3)_3$)

(ii) siloxane having Si-H bonds

tetramethyldisiloxane

(TMDSO:

$(\text{CH}_3)_2\text{HSi-O-SiH}(\text{CH}_3)_2$)

10 These gases are supplied appropriately to the chamber 1 of the film forming portion 101A via branch pipes 9b to 9f and a pipe 9a to which all branch pipes 9b to 9f are connected. Flow rate controlling means 11a to 11e and switching means 10b to 10k for controlling
15 the open ^{ing} and the close ^{ing} of the branch pipes 9b to 9f are provided in the middle of ^{each of} the branch pipes 9b to 9f. A switching means 10a for controlling the open ^{ing} and the close ^{ing} of the pipe 9a is provided in the middle of the pipe 9a.

Also, in order to purge the residual gas ^{from} in the branch
20 pipes 9b to 9e ^{with} by flowing ^{are provided} the N_2 gas, switching means 10l to 10n, 10p for controlling the open ^{ing} and the close ^{ing of communication} between the branch pipe 9f, that is connected to the N_2 gas supply source, and remaining branch pipes 9b to 9e ~~are provided~~.
The N_2 gas purges the residual gas ^{from} in the pipe 9a and the
25 chamber 1 in addition to the branch pipes 9b to 9e.

~~According to~~ ^{Thus,} the film forming equipment 101 ^{includes} described above, the supply source for supplying at least

~~any one of the~~ alkoxy compound having Si-H bonds ^{or} ~~and the~~ siloxane having Si-H bonds and the oxygen-containing gas supply source ~~are provided~~, and also the plasma generating means 2, 3, 7, 8 for plasmanizing the film forming gas, ~~are provided~~.

The insulating film containing Si, O, C, H can be formed by the plasma CVD method by using the above plasma CVD equipment. Therefore, as shown in a second embodiment described in the following, it is possible to form ^{at} ~~the~~ insulating film that has ^a ~~the~~ low dielectric constant, has ^{a low} ~~the small amount of~~ moisture content, is dense and ^{has} ~~is~~ excellent ~~in~~ water resistance. Also, this insulating film has ~~the~~ good adhesiveness to ^{the} ~~the~~ organic coating insulating film or ^{to an} ~~the~~ inorganic coating insulating film, and ^{is more effective in} ~~has the higher capability for~~ preventing the diffusion of copper (Cu).

In particular, the power supplies 7, 8 for supplying ^{at} ~~the powers having two~~ high and low frequencies ^{respectively} ~~to the~~ first and second electrodes 2, 3, ~~of parallel plate type~~ ^{are connected to them}. Therefore, the plasma can be generated by applying the powers ^{at} ~~having these two~~ high and low frequencies to the electrodes 2, 3 respectively. ~~Thus, the insulating film formed in this manner is dense.~~

25 Second Embodiment

~~The examination, made by the inventors of the present invention, about the silicon-containing~~

~~insulating film, that is formed by the above plasma CVD equipment, will be explained hereunder.~~

~~First, the well-known~~ ^{Again, conventional} parallel-plate type plasma CVD equipment is employed as the ~~above~~ plasma CVD equipment. The lower electrode 3 ~~of the upper and lower electrodes 2, 3~~ is also used as a substrate holder, and the heater 12 for heating the substrate is built in the lower electrode 3.

{Formation of Samples}

FIGS. 2A to 2E are sectional views showing samples having the silicon oxide film (a silicon-containing insulating film) of the present ^{embodiment} ~~invention~~.

As shown in FIG. 2A, a sample S1 has a silicon oxide film (this means a silicon-containing insulating film, and referred to as a "PE-CVD TMS SiO₂ film" hereinafter), 42a ~~which is~~ formed by the PE-CVD method using ^a the film forming gas containing trimethoxysilane (TMS), on a silicon substrate 41. For the sake of comparison, a comparative sample CS1 ^{had} ~~having~~ a silicon oxide film (referred to as a "PE-CVD TEOS SiO₂ film" hereinafter) 51a ~~that is~~ formed by the PE-CVD method using ^a the film forming gas containing tetraethoxysilane (TEOS) on the silicon substrate 41, and a comparative sample CS2 ^{had} ~~having~~ a silicon oxide film (referred to as a "PE-CVD SiH₄ SiO₂ film" hereinafter) 52a ~~that is~~ formed by the PE-CVD method using the film forming gas containing monosilane (SiH₄) on the silicon substrate 41, ~~are prepared.~~

As shown in FIG. 2E, a sample S1A ^{was} ~~is~~ formed by further forming an electrode 45 on the PE-CVD TMS SiO₂ film 42a, ^{of} ~~in the~~ sample S1 in which the PE-CVD TMS SiO₂ film 42a is formed on the silicon substrate 41. ^A ~~The~~ mercury probe is employed as the electrode 45, and ^{the} ~~a~~ contact area between the mercury probe and the PE-CVD TMS SiO₂ film 42a ^{was} ~~is~~ 0.0230 cm².

As shown in FIG. 2B, samples S2, S3 ^{were} ~~are~~ formed ^{of} ~~by~~ forming a BPSG film 43 ~~having an amount of~~ ¹²⁰ ~~contained~~ phosphorus ^{having} ~~of~~ 7 mol% and a film thickness of about 500 nm and a PE-CVD TMS SiO₂ film 42b, ~~to be tested~~ in sequence, on the silicon substrate (Si substrate) 41. ~~A film~~ ^{The} thickness of the PE-CVD TMS SiO₂ film 42b ^{was} ~~is set to~~ 100 nm in the sample S2, and ^{the} ~~a film~~ thickness of the PE-CVD TMS SiO₂ film 42b ^{was} ~~is set to~~ 200 nm in the sample S3. For comparison, a comparative sample CS3 employing ^{ed} ~~a~~ PE-CVD TEOS SiO₂ film 51b having a film thickness of 200 nm in place of the PE-CVD TMS SiO₂ film 42b, a comparative sample CS4 employing ^{ed} ~~ing~~ a PE-CVD SiH₄ SiO₂ film 52b having a film thickness of 200 nm ~~similarly~~, and a comparative sample CS5 employing ^{ed} ~~ing~~ a silicon nitride film (referred to as a "PE-CVD SiN film" hereinafter) 53, that ^{was} ~~is~~ formed by the plasma CVD method using the film forming gas containing SiH₄, NH₃ and N₂ ^{and had a} ~~similarly to have a film~~ thickness of 200 nm, ~~are prepared~~.

As shown in FIG. 2C, samples S4, S5 ^{had} ~~are formed by~~ forming low dielectric constant insulating films 44a,

44b and a PE-CVD TMS SiO₂ film 42c ^{formed} in sequence on the silicon substrate (Si substrate) 41. An inorganic coating insulating film 44a ^{was} employed as the low dielectric constant insulating film in the sample S4, and an organic coating insulating film 44b ^{was} employed similarly in the sample S5. For comparison, comparative samples CS6, CS7 employing ^{ed} a PE-CVD TEOS SiO₂ film 51c in place of the PE-CVD TMS SiO₂ film 42c, ~~are formed~~. The inorganic coating insulating film 44a ^{was} employed as the low dielectric constant insulating film in the comparative sample CS6, and the organic coating insulating film 44b ^{was} employed similarly in the comparative sample CS7.

The inorganic coating insulating film ~~is such an~~ ^{was} ~~insulating film that is formed by coating the coating~~ ² liquid such as HSQ (product name: manufactured by Dow Corning Co., Ltd.), MSQ (product name), R7 (product name: Hitachi Chemical Co., Ltd.), etc. ^{In the foregoing, 2} The compound having one carbon or less ^{was used} ~~is distinctively contained as the~~ ~~component compound~~ in the coating liquid. The organic coating insulating film ^{was from 2 of} ~~is formed by coating the coating~~ liquid such as FLARE (product name: manufactured by Allied Signal Co., Ltd.), SiLK (product name: manufactured by The Dow Chemical Co.), etc. ^{in which 2} The compound having two carbons or more is ~~distinctively~~ contained ~~as the component compound~~ in the coating liquid.

As shown in FIG. 2D, a sample S6 ^{was} ~~is~~ formed ^{of, in sequence} ~~by forming~~ a PE-CVD TMS SiO₂ film (lower protection layer) 42d having a film thickness of about 150 nm, a coating insulating film (main insulating film) 44c ^{was} ~~is~~ formed by spin-coating the coating liquid (FOX (product name)), that is produced by dissolving HSQ (Hydrogen silsesquioxane) ~~into~~ the solvent, then baking the coated liquid at the temperatures of 150, 200, and 350 °C for one minute in ~~the~~ nitrogen, respectively, and then curing ~~the resultant~~ at the temperature of 400 °C for 50 minutes in ~~the~~ nitrogen.

~~For comparison,~~ ^{had} a comparative sample CS8 ~~in which~~ a PE-CVD TEOS SiO₂ film 51d ~~is~~ formed in place of the PE-CVD TMS SiO₂ film 42d as the lower protection layer and a comparative sample CS9 ^{had} ~~in which~~ PE-CVD TEOS SiO₂ films 51d, 51e ~~are~~ formed in place of the PE-CVD TMS SiO₂ films 42d, 42e as the upper and lower protection layers, are prepared.

The PE-CVD TMS SiO₂ films 42a to 42e of the samples S1 to S6 ^{were} ~~are~~ formed by using the above ^{described} ~~plasma CVD equipment~~ ^{apparatus} under following film forming conditions.

25 Film forming gas: TMS+N₂O

TMS gas flow rate: 100 sccm

N₂O gas flow rate: 3000 sccm

Gas pressure: 0.7 Torr

Plasmanizing conditions

Power density applied to the upper electrode 2:

0.3 W/cm²

5

(frequency 13.56 MHz)

Power density applied to the lower electrode 3:

0.3 W/cm²

(frequency 380 kHz)

10

In this film-forming apparatus, these power densities correspond ^{to} ~~to the~~ applied power ~~750W~~ to the electrodes, respectively.

Substrate temperature: 300 to 400 °C

Film forming thickness: t nm

15

The above plasma CVD apparatus 101 ^{was} is also employed for forming the PE-CVD TEOS SiO₂ film 51a of the comparative sample CS1, the PE-CVD SiH₄ SiO₂ film 52a of the comparative sample CS2, the PE-CVD TEOS SiO₂ films 51b to 51e of the comparative samples CS3, CS4, CS6 to CS9, ^{2nd} the PE-CVD SiN film 53 of the comparative sample CS5.

20

Following characteristics of the PE-CVD TMS SiO₂ film ⁵ 42a to 42e formed as above ^{were} ~~are~~ examined.

(i) Basic characteristic

25

The film forming rate of the above film forming conditions ^{was 14} ~~is at~~ the range of about 160 to 170 nm/min.

Also, the refractive index of the formed PE-CVD TMS SiO₂ film ^{was 14} ~~is at~~ the range of 1.477 to 1.48, and the film

stress ^{was} ~~is~~ -250 Mpa or 3.0×10^9 dyne/cm². ^{An} ~~The~~ ellipsometer using ~~the~~ He-Ne laser having a wavelength of 6338 angstroms ^{was} ~~is~~ employed to measure the refractive index. Also, the optilever laser scanning system ^{was} ~~is~~ employed to measure the film stress.

Also, the film thickness (t) ^{was} ~~is~~ 500 nm, and the relative dielectric constant of the PE-CVD TMS SiO₂ film ^{was} ~~is~~ 3.9. The sample C1A ^{was} ~~is~~ employed as a sample to examine the relative dielectric constant.

The relative dielectric constant ^{was determined} ~~is calculated~~ ~~based on the result that is obtained~~ by superposing a small signal having a frequency of 1 MHz onto the DC voltage (V) applied between the Si substrate 41 and the electrode 45 in the examined sample S1A, and then measuring the change in ~~the~~ capacitance (C) in response to the change in the DC voltage (V).

(ii) Concentration of Carbon and Nitrogen in the film

~~A~~ concentration of carbon and nitrogen in the PE-CVD TMS SiO₂ film 42a ^{was} ~~is~~ measured by the auger electron spectroscopy method (AES method) using the sample S1.

According to the ~~measuring~~ results, the concentration of carbon ^{was} ~~is~~ 1.0 ^{atomic} ~~atoms~~%, and the concentration of carbon is 2.1 ^{atomic} ~~atoms~~%.

(iii) Film density

The film density of the PE-CVD TMS SiO₂ film 42a ^{was} ~~is~~ examined employing the sample S1 by the well-known

X-ray interference method or weight measuring method.

By way of comparison, similar examinations ^{w2} ~~are~~ carried out ^{for} ~~to~~ the thermal SiO₂ film, the comparative sample CS1 of the PE-CVD TEOS SiO₂ film 51a, and the comparative sample CS2 of the PE-CVD SiH₄ SiO₂ film 52a in place of the PE-CVD TMS SiO₂ film 42a.

As shown in FIGS. 3A and 3B, it ^{w2} ~~is~~ found that the PE-CVD TMS SiO₂ film 42a has ² ~~the high~~ film density of 2.33 ^{higher} ~~rather~~ than other insulating films, and ^{w2} ~~is~~ dense.

(iv) Amount of contained moisture in the film
^{The} ~~An~~ amount of contained moisture in both the film that is obtained immediately after ~~the~~ formation (as deposited) and the film that is left for two weeks in ^{w2} ~~the~~ air ^{is} measured employing the sample S1 by the TDS (Thermal Desorption Mass Spectroscopy) method. This TDS method ^{heats} ~~is the way of heating~~ the sample and then measuring ^{es} ~~ing~~ the molecules emitted from the sample. For the sake of comparison, ² ~~the~~ similar examination ^{w2} ~~is~~ carried out ^{for} ~~to~~ the comparative sample CS1 employing the PE-CVD TEOS SiO₂ film 51a.

^{w2} ~~The~~ Examination ^{was also} ~~is~~ carried out ^{with} ~~by~~ heating the sample from ~~the~~ room temperature to 800 °C ^{using} ~~by the~~ TDS analysis equipment and then ^{finding} ~~quantitating~~ the amount of moisture extracted from the sample.

FIG. 4 is a graph showing the ~~examined~~ results. In FIG. 4, ^{the} ~~an~~ ordinate denotes the amount of moisture (wt%) represented ^{on} ~~in~~ a linear scale and ^{the} ~~an~~ abscissa denotes

the temperature ($^{\circ}\text{C}$) represented ^{on} in a linear scale.

According to the measurement executed immediately after ~~the~~ film formation (as deposited), when the temperature is ^{raised} ~~risen~~ from ~~the~~ room temperature to 800°C ,
 5 the amount of moisture in the PE-CVD TMS SiO_2 film 42a ~~is~~ ^{was} 0.11 wt%, whereas the amount of moisture in the PE-CVD TEOS SiO_2 film 51a ~~is~~ ^{was} 0.49 wt%. In addition, according to the measurement executed two weeks later, the amount of moisture in the PE-CVD TMS SiO_2 film 42a ~~is~~ increased
 10 merely by +0.2 to 0.3 wt% and thus the amount of moisture ~~is~~ seldom varied.

As described above, it is found that both the structural water (the moisture contained in the film due to the film forming gas and the film structure immediately
 15 after the film formation) and the ^{water} physical ^{bed} adsorption ~~water (the incoming moisture that is adsorbed and absorbed physically)~~ in the PE-CVD TMS SiO_2 film 42a ^{were} ~~are~~ small in contrast to the PE-CVD TEOS SiO_2 film 51a.

(v) FT-IR Absorption Intensity

20 ~~Then, examined~~ ^R Results ~~of~~ ^{for} the infrared rays absorption intensity in the sample S1 by the FT-IR analysis method (Fourier Transform Infrared analysis method) are shown in FIG.5A. Similarly, ~~examined~~
 results ~~in the~~ ^{for} comparative samples CS1, CS2 are shown
 25 in FIG.5B.

~~The~~ ^{An} ordinate of FIG.5A denotes the absorption intensity expressed ^{on} in a linear scale (arbitrary unit),

~~an~~ ^{the} abscissa denotes the wave number expressed ^{OR} in a linear scale (cm^{-1}). ~~Similarly,~~ ^{this is true of FIG.5B.}

As shown in FIG.5A, the peak of the infrared rays absorption intensity, having a center wave number in a range of 2270 to 2350 cm^{-1} is confirmed. In contrast, as shown in FIG.5B, such ^{1/2} peak is not ^{seen for} ~~watched in the~~ comparative samples CS1, CS2.

(vi) Water Resistance

The water resistance of the PE-CVD TMS SiO_2 film 42b ^{was examined} ~~is examined~~ by the high pressure humidifying test (pressure-cooker test) ~~while~~ using the samples S2, S3 shown in FIG.2B. By way of comparison, ³ ~~the~~ similar examination ^{was} ~~is~~ applied to the comparative sample CS3 employing the PE-CVD TEOS SiO_2 film 51b in place of the PE-CVD TMS SiO_2 film 42b and the comparative sample CS5 employing the PE-CVD SiN film 53, ~~similarly~~.

The conditions of the high pressure humidifying test are given as follows. The ^{of exposure was} ~~leaving time~~ is used as a parameter.

20 Temperature: 121 °C

Pressure: 2.0 atm

Humidity: 100 % R.T. (Room Temperature)

Evaluation of the water resistance ^{was} ~~is~~ carried out by evaluating ^{the} ~~an~~ amount of P=O bonds contained in the examined insulating film after the high pressure humidifying test. In order to evaluate the amount of P=O bonds contained in the BPSG film 43, the P=O

absorption coefficient ^{was} ~~is~~ measured by the FT-IR analysis method. If ~~the~~ moisture enters into the BPSG film 43, the P=O bonds in the film react with the moisture ^{and are} ~~to~~ ^{thereby} ~~destroyed~~. In this case, if the PE-CVD TMS SiO₂ film 42b ~~for~~ covering the BPSG film 43 has ~~the~~ ^{allow} high water resistance, such film does not pass through the moisture to and thus the P=O bonds in the BPSG film 43 are ~~never~~ ^{not} destroyed. As a result, it is possible to say that, ~~if~~ ^{as} the time dependent change of the P=O absorption coefficient becomes smaller, the water resistance becomes higher.

FIG.6 is a graph showing the time dependent change of ~~an~~ ^{the} amount of contained phosphorus in the insulating film after the high pressure humidifying test is carried out. ^{The} An ordinate denotes the P=O absorption coefficient (arbitrary unit) expressed ^{on} in a linear scale, and ^{the} an abscissa denotes the ^{exposure} ~~leaving~~ time (H (hour)) expressed ^{on} in a linear scale.

Based on the results shown in FIG.6, it is found that, even after both the samples S2, S3 are left for 150 hours as they are, their P=O absorption coefficients are seldom changed from the initial P=O absorption coefficient, regardless of the magnitude of the thickness of the PE-CVD TMS SiO₂ film 42b, like the PE-CVD SiN film 53 in the comparative sample CS5, i.e., the PE-CVD TMS SiO₂ film 42b has ~~the~~ ^{that of} water resistance equivalent to the PE-CVD SiN film 53.

Also, the water resistance ^{was} ~~is~~ examined by another high pressure humidifying test ^{applied to} ~~while using the examined~~ sample S3 and the comparative samples CS3 ^{and} CS4.

5 ^{were} The conditions of the high pressure humidifying test ~~are~~ the same as above.

The results are shown in FIG.7. ^{The} An ordinate of FIG.7 denotes the water resistance (%) expressed ^{on} ~~in~~ a linear scale, and ^{the} ~~an~~ abscissa denotes the ^{exposure} ~~leaving~~ time (H (hour)) expressed ^{on} ~~in~~ a linear scale. ~~The sample S3 and the comparative samples CS3, CS4 are used as a parameter.~~

^{In the manner described} ~~Like the above, the~~ evaluation of the water resistance ^{was} ~~is~~ carried out by ^{determining the} ~~evaluating an~~ amount of P=0 bonds contained in the examined insulating film after the high pressure humidifying test. The water resistance in FIG.7 is derived by calculating the P=0 absorption coefficient obtained after the high pressure humidifying test on the basis of the P=0 absorption coefficient before ^{taken} ~~the leaving-off, that is assumed~~ as 100.

20 As shown in FIG.7, it ^{was} ~~is~~ found that the sample S3 ^{had} ~~has~~ the water resistance of 97.4 % (100 H), ^{a value} ~~that exceeds~~ ^{ing} the comparative samples CS3, CS4.

(vii) Leakage current of the film
25 ^A ~~The examined sample S1A shown in FIG.2E is formed.~~ ^{was formed as}
That is, the electrode 45 ^{was} ~~is~~ formed on the PE-CVD TMS SiO₂ film 42 having a film thickness (t) of 200 nm ^{on} ~~in~~ the

sample S1 according to the present invention.

The leakage current flowing through the silicon substrate 41 and the electrode 45 ^{was} is measured by applying ~~the~~ voltage between the silicon substrate 41 and the electrode 45. The silicon substrate 41 ^{was} is grounded, and ^a the negative voltage ^{was} is applied to the electrode 45.

According to the results, the leakage current of the PE-CVD TMS SiO₂ film 42a ~~as the single substance is~~ ^{was} on the order of 10⁻⁸ A/cm² at ^{an} the electric field strength of 5 MV/cm, and the breakdown voltage ^{was} is about 10 MV/cm in terms of the electric field.

(viii) Adhesiveness of the film

The adhesiveness between the PE-CVD TMS SiO₂ film 42c according to the present invention and the underlying low dielectric constant insulating film 44a, 44b ^{was} is examined ~~employing the~~ ^{for} samples S4, S5. Also, ^a the sample which ^{was} is subjected to the surface treatment prior to the film formation and ² the sample which ^{was} is not subjected to the surface treatment ^{were} are prepared, and then ^{examined in} the similar ^{fashion} examination is carried out. The surface treatment executed prior to the film formation ^{was} is ~~the treatment~~ ^{of} for reforming the surface of the processed film ² employing ~~the~~ plasma of N₂, NH₃, H₂, etc.

By way of comparison, the PE-CVD TEOS SiO₂ film 51c ^{was} is employed in place of the PE-CVD TMS SiO₂ film 42c, and similar examinations ^{were} are carried out employing the inorganic coating insulating film 44a (the comparative

sample CS6) and the organic coating insulating film 44b (the comparative sample CS7) as the low dielectric constant insulating film.

5 ~~As the test~~³ for examining the adhesiveness of the film, ~~the peel test~~² ~~by~~ using the tape and ~~the peel test~~^a by the CMP (Chemical Mechanical Polishing) ~~on~~^{over} the entire surface of the wafer ~~are~~^{were} carried out.

10 According to the ~~examined~~^{of examination} results, regardless of the ~~presence~~^{use} of the surface treatment prior to the film formation, the PE-CVD TMS SiO₂ film 42c ~~has~~^{showed} the good adhesiveness to the inorganic coating insulating film 44a and the organic coating insulating film 44b. In contrast, ~~the~~^{the} degree of the adhesiveness of the PE-CVD TEOS SiO₂ film 51c ~~is~~^{was} inferior to ~~the~~^{that of} the PE-CVD TMS SiO₂ film 42c as a whole. ~~Then, difference in the adhesiveness~~^{and a} ~~differed according~~^{was} ~~appeared in response~~^{was} to whether or not the surface treatment ~~is~~^{was} applied prior to the film formation. That is, the sample which ~~is~~^{was} subjected to the surface treatment prior to the film formation had ~~the~~^{was} higher adhesiveness than the sample which ~~is~~^{was} not subjected to the surface treatment.

15

20

(ix) Defect Generating Rate due to Heat Cycle

25 The defect generating ~~rate~~^{ion} due to the heat cycle ~~about~~^{for} the sample S6 and the comparative samples CS8, CS9 ~~is~~^{was} examined. Respective samples ~~are~~^{were} sealed in the package. Test conditions of the heat cycle ~~are given~~^{were} as follows. The cycle number is used as a parameter.

High temperature (holding time): 150 °C (20 minutes)

Low temperature (holding time): -55 °C (20 minutes)

5 Cycle number: 100, 200, 300, 500 °C

The results are shown in FIG.9. ^{The} An ordinate ⁱⁿ of FIG.9 denotes the defect generating ^{ion} rate (%) expressed ^{on} in a linear scale, and ^{the} an abscissa denotes the types of ~~the~~ sample. ^{5 were} The ~~types of the sample~~ are the sample S6, ^{and} and the comparative samples CS8/CS9, as explained above, in order from the left side. The partition area indicated by a bar graph denotes ^{the} a fraction defective ^{for} at a particular cycle number, ^{i.e.} the partition area hatched by lateral lines denotes the fraction defective at 100 °C, 15 the partition area hatched by vertical lines denotes the fraction defective at 200 °C, the partition area hatched by oblique lines denotes the fraction defective at 300 °C, and the white partition area on a black ^{back} ground denotes the fraction defective at 500 °C.

20 As shown in FIG.9, in ~~the~~ sample S6 employing ^a the silicon oxide film of the present invention as both the upper protection layer and the lower protection layer, ^{3 were} the defect ^{amount of} is generated at 300 °C or more, but the defects generating ^{ed was} rate is about 2 to 3 % even if the defects generating ^{ed} rates at 300 °C and 500 °C are added. In the 25 comparative sample CS8 employing the silicon oxide film 52d of the present invention only as the lower protection

layer ~~out of the upper protection layer and the lower~~
~~protection layer, the defect~~ ^{is were} generated almost
 uniformly from 100 °C to 500 °C, and the defect
 generating ~~rate~~ ^{ed were} is about 25 % in total. In the
 5 comparative sample CS9 not employing the silicon oxide
 film 42d, 42e of the present invention, ^{as both} ~~the~~ upper
 protection layer and ^{as a} ~~the~~ lower protection layer, the
 defect ^{is were} generated from 100 °C to 500 °C. In particular,
 the defect ^{ed} generating ~~rate~~ at 300 °C and 500 °C ~~are~~
 10 increased, ^{so that} and the defect ^{generated totaled} generating ~~rate~~ is about 53 %,
~~in total.~~

CU

(x) Examination of the ~~v~~ barrier characteristic ~~to~~
~~the copper (Cu)~~

(a) TDDB (Time Dependent Dielectric Breakdown) test

15 The TDDB test measures ^{the} ~~a~~ time required to come up
 to the dielectric breakdown when ^a ~~the~~ voltage is applied
 to the sample.

was

The examined sample ~~is~~ ^{was} prepared by stacking the
 PE-CVD TMS SiO₂ film according to the present invention
 20 and the Cu film on the Si substrate in sequence. ~~By way~~
^{For} ~~of~~ comparison, ^a ~~the similar examination is applied to the~~
 sample employing the PE-CVD TEOS SiO₂ film in place of
 the PE-CVD TMS SiO₂ film, and ^a ~~the~~ sample interposing the
 TiN film between the Cu film and the PE-CVD TEOS SiO₂ film. ^{were utilize}

25 ~~According to the examined results,~~ ^{The} ~~the~~ breakdown
 lifetime of 10×10^5 seconds ^{showed a} ~~is~~ obtained at the electric
 field strength of 8 MV/cm. ³⁷

In contrast, in the sample employing the PE-CVD TEOS SiO₂ film, ³ⁿthe electric field strength ^{of} ~~is~~ 8 MV/cm ^{resulted in a} ~~to get~~ ~~the~~ breakdown lifetime on the order of 10×10^5 seconds. This means that the breakdown lifetime of the sample employing the PE-CVD TMS SiO₂ film ^{was} ~~is~~ longer by almost six figures than the sample employing the PE-CVD TEOS SiO₂ film.

In the sample interposing the TiN film between the Cu film and the PE-CVD TEOS SiO₂ film, ³ⁿthe electric field strength ^{of} ~~is~~ 7.5 MV/cm ^{resulted in a} ~~to get~~ the breakdown lifetime on the order of 10×10^5 seconds.

With the above, it is possible to say that the sample employing the PE-CVD TMS SiO₂ film has ^athe longer breakdown lifetime by almost six figures ^{that of} than the sample employing the PE-CVD TEOS SiO₂ film and ^{serves as a} ~~has the~~ barrier ^{exceeding that of} ~~characteristic to Cu, that is equivalent to or more than~~ the TiN film.

(b) Examination of heat resistance

As shown in FIG.10, ³the ~~examined~~ sample ^{was} ~~is~~ prepared by stacking the PE-CVD TMS SiO₂ film of 125 nm ⁱⁿ thickness according to the present invention and the Cu film on the Si substrate (not shown) ^{In} ~~to~~ contact ^{with} ~~to~~ each other. ^{the distribution of} ~~The examination is made By~~ measuring the Cu concentration ~~distribution state~~ in the PE-CVD TMS SiO₂ film ~~on the basis of the state~~ obtained immediately after the film formation (indicated by a dotted line in FIG.10), after the sample is processed for a predetermined time

~~three types~~ i.e., 1 hour (chain double-dashed line),
7 hours (solid line), and 15 hours (dot-dash line)) at
²~~the~~ temperature of 470 °C.

FIG.10 is a graph showing the ~~examined~~ results. In
5 FIG.10, ^{the}~~an~~ ordinate on the left side denotes ~~a~~ Cu
concentration and ~~a~~ Si concentration (cm^{-3}) represented
~~on~~ in a logarithmic scale. ^{The}~~An~~ abscissa denotes ~~a~~ depth (nm)
measured from one surface of the PE-CVD TMS SiO_2 film
toward the Cu film side and represented ¹⁵~~in~~ ^{on} a linear scale.

10 As shown in FIG.10, the distribution ~~is~~ seldom
changed ⁵~~from the distribution~~ ^{that} obtained immediately after
the film formation. In other words, it is found that
the PE-CVD TMS SiO_2 film has ¹⁵~~the~~ ²sufficient ¹⁵~~barrier~~ ⁵⁰⁰
~~characteristic to the~~ Cu.

15 In the above, the alkoxy compound (^{ex.} TMS) having
Si-H bonds is employed as the silicon-containing gas in
the film forming gas. But ^{3.1}~~the~~ siloxane having Si-H bonds
may be employed.

^{While}
20 ~~Also,~~ N_2O is employed as the oxygen-containing gas
in the above, ^{5.25}~~But any one~~ selected from the group
consisting of oxygen (O_2), nitrogen dioxide (NO_2), carbon
monoxide (CO), carbon dioxide (CO_2) and water (H_2O) may
be employed.

In addition, if ~~any one selected from the group~~
25 ~~consisting of~~ hydrogen (H_2) ^{or} and nitrogen (N_2) is added
to the above film forming gas, the density can be further
enhanced.

Third Embodiment

Next, a semiconductor device and a method of manufacturing the same according to a third embodiment of the present invention will be explained with reference to FIGS. 11A and 11B hereunder.

~~FIG. 11B is a sectional view showing a semiconductor device according to a third embodiment of the present invention.~~

As shown in FIG. 11B, ^athe silicon oxide film (the silicon-containing insulating film) 24 according to the present invention is formed on the substrate 20a. ~~In~~ ^{consists of} the substrate 20a, the underlying insulating film 22 and the wiring 23, ^{both} ~~are~~ formed on the base substrate 21. The silicon oxide film 24 covers the wirings 23. In the silicon oxide film 24 according to the present invention, ^{the} ~~a~~ peak ~~of an~~ absorption intensity ~~of an~~ infrared rays ^{was} ~~is~~ in a range of ^{was} ~~a~~ wave number, 2270 to 2350 cm^{-1} , ~~a~~ film density ^{was} ~~is~~ in a range of 2.25 to 2.40 g/cm^3 , and ~~a~~ relative dielectric constant ^{was} ~~is~~ in a range of 3.3 to 4.3.

In this case, the silicon substrate or the base substrate obtained by forming the wirings and the insulating film on the silicon substrate may be employed as the base substrate 21. ^A ~~The~~ conductive material such as aluminum, copper, etc. may be employed as the material of the wirings 23.

~~In this manner,~~ ^{Thus} the silicon oxide film 24 according to the present invention may be employed as the insulating

film that covers the wirings 23, ~~made of the conductive material, such as aluminum, copper, etc.~~

In 2
~~According to the semiconductor device of the third~~
 embodiment, the silicon-containing insulating film 24
 5 according to the present invention is formed ⁱⁿ ~~to come into~~
 contact with ^{the wirings 23 and to cover the wirings 23.} ~~the wirings 23 and to cover the wirings 23.~~

described
 The above silicon-containing insulating film 24 ~~has~~
~~qualities such that the insulating film is dense, is~~ *has*
 excellent ~~in the~~ water resistance, and ~~has the~~ small
 10 amount of ~~contained~~ moisture ^{those of 2} ~~in the film~~, which are ^a ~~qualities~~
 equivalent to the silicon nitride film, and also has the
 smaller relative dielectric constant ^{that of 2} ~~than the~~ silicon
 nitride film. As a result, if the silicon-containing
 insulating film according to the present invention is
 15 employed as the protection layer 24 ~~for~~ covering the
 wirings 23, etc., ~~the~~ corrosion of the wirings 23 can
 be prevented by preventing ^{moisture} ~~the permeation of the incoming~~
~~moisture~~, while reducing the parasitic capacitance
 between the ^{wires of} wirings 23.

illustrating steps in
 20 FIGS. 11A and 11B are sectional views ~~showing~~ the
 method for manufacturing the semiconductor device
 according to the third embodiment of the present
 invention. TMS+N₂O is employed as the film forming gas
 for the PE-CVD TMS SiO₂ film according to the present
 25 invention.

First, as shown in FIG. 11A, an underlying insulating
~~film 22 made of the~~ *22* PE-CVD TMS SiO₂ film is formed on the

silicon substrate 21 by the plasma CVD method using TMS+N₂O as the film forming gas.

In order to form the PE-CVD TMS SiO₂ film, first the silicon substrate 21 is loaded into the chamber 1 of the plasma film forming ^{apparatus} equipment 101 and held by the substrate holder 3. Then, the silicon substrate 21 is heated to ^{maintain a} ~~hold at~~ the temperature of 350 °C. TMS and the N₂O gas are introduced into the chamber 1 of the plasma film forming ^{apparatus} equipment 101 shown in FIG.1 at flow rates of 100 sccm and 3000 sccm, respectively, to hold the pressure at 0.7 Torr. Then, ^{of} ~~the~~ power 0.3 W/cm² ^{at} having the frequency of 380 kHz is applied to the lower electrode 3 and also ^{of} ~~the~~ power 0.3 W/cm² ^{at} having the frequency of 13.56 MHz is applied to the upper electrode 2, thereby ^{converting the} ~~Accordingly,~~ TMS and N₂O ^{into a} ~~are~~ plasma^{ized}. ⁱⁿ ~~The~~ PE-CVD TMS SiO₂ film 22 of about 200 nm thickness is formed while holding this condition for a predetermined time. ~~According to the examination,~~ ^{thus} ~~the~~ formed PE-CVD TMS SiO₂ film 22 ^{was found to have a} ~~had the~~ relative dielectric constant of about 3.9 ^{as} ~~that is~~ measured at ^a ~~the~~ frequency of 1 MHz, and ^a ~~the~~ leakage current of 10⁻⁸ A/cm² at ^{on} ~~the~~ electric field strength of 5 MV/cm.

~~Then, the~~ wiring (lower wiring) 23 ^{was then} ~~is~~ formed on the underlying insulating film 22. Then, as shown in FIG.11B, ^{was} ~~the~~ PE-CVD TMS SiO₂ film 24 of about 500 nm ^{same} ~~thickness~~ is formed by the plasma CVD method ^{described} ~~that is~~ used to form the above PE-CVD TMS SiO₂ film 22.

As described above, according to the third embodiment of the present invention, the underlying insulating film 22 is formed on the silicon substrate 21 before the wiring 23 is formed. The PE-CVD TMS SiO₂ film is dense, has ~~the~~ good water resistance, and has ^{low} ~~the small~~ amount of contained moisture in the film. Therefore, the underlying insulating film 22 can prevent ~~the moisture in the underlying insulating film 22 and the incoming~~ moisture from reaching the silicon substrate 21.

Also, since the leakage current between the wiring 23 and the silicon substrate 21 ^{is} ~~can be~~ suppressed, the transistors, the capacitance^{ors}es of the memory elements, etc. are covered with the PE-CVD TMS SiO₂ film, ~~in case~~ they are formed on the silicon substrate 21. Therefore, ~~the flowing out~~ ^{leakage} of the accumulated charge can be prevented and thus the reliability of the device can be improved.

In addition, since the PE-CVD TMS SiO₂ film 24 is formed after the wiring 23 is covered, ~~the~~ corrosion of the wiring 23 due to ~~the~~ moisture in the film 24 and ~~the~~ ^{ambient} incoming moisture can be prevented.

Further, since the PE-CVD TMS SiO₂ film 24 has ² ~~the~~ lower relative dielectric constant than ^{that of} the silicon nitride film and ^{the} ~~the~~ small leakage current, the leakage current between the ^{wires as the} wirings ~~can be~~ ^{is} suppressed and the parasitic capacitance between the ^{wires} wirings can be reduced.

both for
~~in the situation that a plurality of wirings are provided~~
wires and for
~~adjacently of the multi-layered wiring, is formed.~~

Fourth Embodiment

Next, a semiconductor device and a method of manufacturing the same according to a fourth embodiment of the present invention will be explained with reference to FIGS. 12A to 12C ~~hereunder~~.

FIG. 12C is a sectional view showing a semiconductor device according to a fourth embodiment of the present invention.

As shown in FIG. 12C, ~~the~~ ^a low dielectric constant insulating film 25 such as ~~the~~ ^a porous insulating film, ^a the SiOF film, or the like is formed to cover the wirings 23, and then the protection layer 26 made of the silicon oxide film (silicon-containing insulating film) of the present invention is formed on the insulating film 25.

In the silicon oxide film 26 of the present invention, ^{infrared ray} the peak of the absorption intensity ~~of the infrared rays~~ is in ^a the range of ~~a~~ wave number 2270 to 2350 cm^{-1} , the film density is in the range of 2.25 to 2.40 g/cm^3 , and the relative dielectric constant is in the range of 3.3 to 4.3.

^{Thus, the} ~~The above~~ silicon oxide film 26 has ~~the~~ qualities which are equivalent to ^{those of 2} the silicon nitride film. The silicon oxide film 26 has ^{a low} ~~the small~~ relative dielectric constant, is dense, ^{has} ~~is~~ excellent in the water resistance, and has ~~the small amount of contained~~ ^{a lot} moisture ^{content} in the

~~film.~~ Accordingly, if the silicon-containing insulating film according to the present invention is employed as the protection layer 26 that covers the wirings 23, etc., ~~the~~ corrosion of the wirings 23 can be prevented by preventing the permeation of ~~the incoming~~ moisture, while reducing the parasitic capacitance between the ^{wires of} wirings 23.

In particular, if ~~the~~ porous insulating film having ~~the~~ high hygroscopicity is employed as the insulating film 25 that covers the wirings 23, ~~the incoming~~ ^{ingress} of the moisture into the porous insulating film can be prevented and also the increase in the dielectric constant due to ~~the~~ moisture absorption can be prevented.

FIGS. 12A to 12C are sectional views showing the method of manufacturing the same according to the fourth embodiment of the present invention. TMS+N₂O is used as the film forming gas.

First, as shown in FIG. 12A, like the third embodiment, ~~the~~ ^a underlying insulating film 22 made of the PE-CVD TMS SiO₂ film is formed on the silicon substrate (base substrate) 21 by the plasma CVD method using TMS+N₂O as the film forming gas. ^{thus} The formed PE-CVD TMS SiO₂ film 22 had ~~the~~ ^a relative dielectric constant of about 3.9 ~~that~~ ^{had a} is measured at ~~the~~ ³ frequency of 1 MHz, and ~~the~~ leakage current of 10⁻⁸ A/cm² ^{in an} at ~~the~~ electric field strength of 5 MV/cm.

Then, the wiring (lower wiring) 23 is formed on the

underlying insulating film 22. ^{Next} Then, as shown in FIG.12B, a porous insulating film 25 having ^a the low dielectric constant and the film thickness of about 500 nm is formed by the ^{conventional} well-known method. ^{to complete} These elements

5 constitute a substrate 20b.

Then, as shown in FIG.12C, a protection film 26 ^{i.e.} made of the ^a PE-CVD TMS SiO₂ film and having the film thickness of about 200 nm, is formed by the plasma CVD method that is used to form the above PE-CVD TMS SiO₂ film 22.

10 As described above, according to the fourth embodiment, the protection film 26 ~~made of the~~ (PE-CVD TMS SiO₂ film) is formed on the porous insulating film 25 that covers the wiring 23. The PE-CVD TMS SiO₂ film is dense, has the good water resistance, and has the small amount of ^{is low} contained moisture in the film.

15 Therefore, the protection film 26 can prevent the ^{ambient} incoming moisture from reaching the wiring 23. Also, the leakage current of the overall interlayer insulating film, including the porous insulating film 25, can be ^{reduced} suppressed.

20

Fifth Embodiment

Next, a semiconductor device and a method of manufacturing the same according to a fifth embodiment of the present invention will be explained with reference to FIGS.13A to 13F hereunder.

25

^{Not} → FIGS.13A to 13F are sectional views showing the semiconductor device and the method of manufacturing the

~~same according to the fifth embodiment of the present invention.~~ In this case, like the third embodiment, TMS+N₂O is used as the film forming gas.

FIG. 13F is a sectional view showing a semiconductor device according to a fifth embodiment of the present invention.

As shown in FIG. 13F, in the semiconductor device, an underlying insulating film 32 is formed on a base substrate 31, and a lower wiring 33 is formed thereon. Further, an interlayer insulating film is formed ^{with end covering} ~~to~~ the lower wiring 33 ~~and to cover the lower wiring 33.~~ The same base substrate ~~as the base substrate~~ ^{as shown} 21 in FIG. 11B may be employed as the base substrate 31.

The interlayer insulating film is formed by laminating a lower protection layer 34, formed of the silicon-containing insulating film according to the present invention, a main insulating film 35, and an upper protection layer 36, formed of the silicon-containing insulating film according to the present invention, in sequence from the lower layer. In the silicon-containing insulating film according to the present invention, ^{the} a peak of the ^{infrared} absorption intensity ~~of the infrared rays~~ is in a range ~~of~~ the wave number ~~of~~ 2270 to 2350 cm⁻¹, a film density is in a range of 2.25 to 2.40 g/cm³, and a relative dielectric constant is in a range of 3.3 to 4.3.

In this ^{embodiment} case, the porous insulating film or the SiOF

film, that is the insulating film having ^a the low dielectric constant, may be employed as the main insulating film 35.

Also, ~~a~~ via hole 37 is formed in the interlayer insulating film ^{covering} over the lower wiring 33, ^{and} the lower wiring 33 and the upper wiring 38 are connected ^{through} via this via hole 37.

As described above, according to ^{this} the fifth embodiment, since the lower protection layer 34 made of the PE-CVD TMS SiO₂ film ~~is formed to~~ ^s cover the lower wiring 33, the corrosion of the lower wiring 33 due to the moisture contained in the lower protection layer 34 and the ~~incoming~~ ^{ambient} moisture can be prevented.

Further, the upper and lower protection layers 34, 36 made of the PE-CVD TMS SiO₂ film ~~are formed to put~~ ^{sandwich} the main insulating film 35 therebetween.

If the main insulating film 35 is formed of ~~the~~ SiOF ~~film~~, the diffusion of ^{elemental} the fluorine (F) ~~element~~ into the outer peripheral portions of the upper and lower protection layers 34, 36 can be prevented.

^{In contrast,} otherwise, if the main insulating film 35 is ~~formed~~ ² of the porous insulating film, the hygroscopicity is high and the dielectric constant ~~is ready to~~ ^{is} vary due to the moisture absorption. However, if the main insulating film 35 is sandwiched ^{between} by the upper and lower protection layers 34, 36, the permeation of ^{ambient} ~~the incoming~~ moisture into the main insulating film 35 can be ^{reduced} suppressed and

thus the dielectric constant of the interlayer insulating film ^{is} ~~can be~~ ^{at a} stabilized with low value. Also, the leakage current of the overall interlayer insulating film containing the porous insulating film 35 can be suppressed.

5 ~~Furthermore,~~ ^{Because} the PE-CVD TMS SiO₂ films 34, 36 ^{have} ~~has~~ ^{a low} the small relative dielectric constant ~~rather than the~~ ^{low} silicon nitride film, and ~~has the small~~ leakage current, ^{the of} ~~Therefore,~~ in case ^{close} a plurality of wirings ~~are~~ arranged ^{close} closely or a multi-layered wiring is formed, the leakage current between the wirings can be suppressed and also the parasitic capacitance between the wirings can be reduced.

15 ~~In this case,~~ ^{When} if the underlying insulating film 32 formed on the base substrate 31 is ~~formed of the~~ ^{is a} PE-CVD TMS SiO₂ film according to the present invention, the ^{permeation} ~~reaching of the~~ moisture in ^{to} the underlying insulating film 32 and ~~the incoming moisture~~ to the base substrate 31 can be prevented. ~~Also,~~ ^{also} if the silicon ~~substrate~~ is employed as the base substrate 31, the leakage current ^{is reduced} between the lower wiring 33 and the base substrate 31. ~~Therefore, in case the transistors, the capacitors of the memory devices, etc. are formed on the silicon substrate, they are covered with the PE-CVD TMS SiO₂ film and,~~ ^a ~~As a result, the flowing out of the accumulated charges~~ ^{leakage} can be prevented and thus the reliability of the device can be improved.

illustrating steps in

FIGS.13A to 13F are sectional views ~~showing~~ the method of manufacturing the semiconductor device according to the fifth embodiment of the present invention. In this ~~case~~ ^{fifth embodiment, as in} like the third embodiment, 5 TMS+N₂O is used as the film forming gas.

FIG.13A is a sectional view showing the state after the wiring is formed. In FIG.13A, ~~a reference~~ 31 denotes a silicon substrate(base substrate); 32, an underlying insulating film; and 33, ~~A~~ wiring (lower wiring). If 10 the wiring 33 is ~~the~~ copper wiring, a TaN film serving as ~~the~~ ^{for} copper barrier to the underlying insulating film 22 and a Cu film formed by ~~the~~ ^{sputter} sputter, although not shown, are formed between the underlying insulating film 32 and the wiring (lower wiring) 33, ~~from the bottom~~. These 15 films constitute the substrate 20c.

In this state, as shown in FIG.13B, a barrier insulating film (lower protection layer) 34 ~~made of the~~ ^{having a} PE-CVD TMS SiO₂ ~~film having a film~~ thickness of about 50 nm is formed on the wiring 33 by the plasma CVD method 20 using TMS+N₂O.

The barrier insulating film 34 is formed by the same manufacturing method as the underlying insulating film 22 in the third embodiment. ^{Because the} The same film forming conditions are employed, their explanation will be omitted herein. According to the examination, the 25 formed barrier insulating film 34 ^{was found to have} ~~has~~ the relative dielectric constant of about 3.9 ~~that is~~ measured at the ^a

frequency of 1 MHz, and ^athe leakage current of 10^{-8} A/cm² ^{in an} at the electric field strength of 5 MV/cm.

Then, as shown in FIG.13C, a porous insulating film 35 having ^athe low dielectric constant and ²the film thickness of about 500 nm is formed by ^{a conventional} the well-known plasma CVD method. ~~As the method of forming the porous insulating film, there are the method of forming a multi-layered insulating film by repeating the film formation by the low pressure thermal CVD method and the film formation by the plasma CVD method, the method of laminating the organic film and the SiO₂ film alternatively and then removing the organic film by ashing using the oxygen plasma, etc., for example.~~ ^{may be formed as}

^{Next} Then, as shown in FIG.13D, a thin and highly dense NSG film (silicon oxide film not^{an} containing ~~the~~ impurity), that serves as a protection film (upper protection layer) 36 for the porous insulating film 35 in ~~the~~ ashing and ~~the~~ etching, is formed. If no protection film 36 is formed, the quality of the porous insulating film 35 is altered by the processing gas when ~~the ashing of the photoresist film is executed~~ or when the barrier insulating film 34 under the porous silicon-containing insulating film 35 is etched, and thus there is the possibility that the low dielectric constant characteristic is ^{lost} degraded. The protection film 36 may be omitted, ~~as the case may be.~~

Then, as shown in FIG.13E, a photoresist film (not

shown) is formed ^{with} and then an opening ~~portion is formed~~
in the via-hole forming-area ~~of the photoresist film~~ by
patterning the photoresist film. Then, ~~first~~ the
protection film 36 is etched and removed ^{through} via the opening
5 ~~portion~~ in the photoresist film by ~~the~~ reactive ion
etching (RIE) using ^a ~~the~~ ^{of} ~~plasma~~ ~~mixed gas~~ containing
 $\text{CF}_4 + \text{CHF}_3$. Then, the porous insulating film 35 is etched
and removed by using ^a the mixed gas containing $\text{CF}_4 + \text{CHF}_3$,
^{in a} ~~whose composition ratio is changed from~~ ^{different than that of} the gas used in
10 the etching of the protection film 36. Accordingly, an
opening ~~portion~~ is formed to expose the barrier
insulating film 34. ~~Then, the ashing of the photoresist~~
^{then removed by ashing.} film is ~~executed.~~ ~~At this time,~~ The barrier insulating
film 34 has ~~the etching~~ resistance against the etching
15 gas for the porous insulating film 35 and the ashing gas
for the photoresist film. As a result, the wiring 33
is not ^{adversely} ~~badly~~ affected by the etching gas, etc. ~~The~~
concentration of the mixed gas containing $\text{CF}_4 + \text{CHF}_3$ may
be adjusted by adding $\text{Ar} + \text{O}_2$, etc. ~~in addition to etching~~
20 ~~gas.~~

Then, the barrier insulating film 34 is etched and
removed via the opening ~~portion~~ in the protection film
36 and the opening ~~portion~~ in the porous insulating film
35 by ~~the~~ reactive ion etching (RIE) using ^a ~~the~~ ~~plasma~~ ~~mixed~~
25 ^{of a} mixed gas containing $\text{CF}_4 + \text{CHF}_3$, that has the same
composition ~~ratio~~ as the gas used in the etching of the
above protection film 36. Accordingly, a via hole is

formed to expose the barrier insulating film 34 ~~from its~~
~~bottom portion.~~ At this time, ^{the} lower wiring 33 ^{is} ~~has~~
~~the etching resistance against the etching gas for the~~
~~above barrier insulating film 34.~~ ^{protected from} ~~and, as~~ As a result, the lower
 5 wiring 33 is not badly affected by the etching gas. In
 this case, ^{the} ~~a~~ surface of the lower wiring 33 is oxidized.
 But such oxide film may be removed by exposing to ~~the~~ ^a
 hydrogen plasma diluted with a reducing gas, e.g., an
 inert gas such as NH_3 , argon, nitrogen, or the like after
 10 the ashing ~~step~~ of the photoresist film and the etching
~~step~~ of the barrier film are completed.

~~Then,~~ ^{Next} As shown in FIG. 13F, a conductive ^{or} ~~film~~ is ~~then~~
 filled in the via hole 37. ~~Then,~~ ^{Next} an upper wiring 38 made
 of copper or aluminum is formed ^{and} ~~to be~~ connected to the
 15 lower wiring 33 ^{through the} ~~via the~~ ^{hole 37} ~~conductive film.~~ If the upper
 wiring 38 is ~~the~~ copper wiring, an underlying conductive
 film consisting of a barrier metal film, e.g., such as
 a tantalum nitride (TaN), ^{is provided} ~~and~~ a copper film formed by ~~the~~
 sputter ^{and} ~~method~~ is provided in the via hole 37, and then
 20 the conductive film is formed thereon.

With the above, the formation of the upper wiring
 38 is completed. The upper wiring 38 is connected to
 the lower wiring 33 ^{through} ~~via~~ the via holes in the protection
 film 36, the porous insulating film 35, and the barrier
 25 insulating film 34.

As described above, according to the fifth
 embodiment, the lower wiring 33 is covered with the

barrier insulating film 34, ^{i.e.} ~~made of~~ the PE-CVD TMS SiO₂ film ^{of} ~~to which~~ the present invention, ~~is applied.~~

~~By the way, as indicated by the examined results~~ ^{The} ~~obtained~~ ^{show that} in the second embodiment, ^{the} PE-CVD TMS SiO₂ film according to the present invention has ~~the~~ ^{those of a} qualities equivalent to ~~the~~ ^{has} silicon nitride film. The PE-CVD TMS SiO₂ is dense, ^{is} ~~excellent in the~~ water resistance, and has ~~the small amount of contained moisture~~ ^{2 low} ~~in the film.~~ ^{content} Accordingly, ~~the~~ corrosion of the lower wiring 33 can be prevented by preventing the permeation of ~~the incoming~~ moisture.

In addition, if the underlying insulating film 32 is formed of the PE-CVD TMS SiO₂ film according to the present invention, all peripheral portions of the lower wiring 33 can be protected by the PE-CVD TMS SiO₂ film. Therefore, ~~the~~ corrosion of the lower wiring 33 ^{is further} ~~can be~~ prevented ~~much more~~ ^{in of} by preventing ~~the~~ permeation of ~~the~~ moisture from ~~all~~ ^{the} peripheral portions of the lower wiring 33.

Further, upper and lower surfaces of the porous insulating film 35 having the low dielectric constant are protected by the barrier insulating film 34 formed of the PE-CVD TMS SiO₂ film and the protection film 36 formed of the PE-CVD TMS SiO₂ film. Accordingly, ~~the~~ permeation of ~~the incoming~~ moisture into the porous insulating film 35 can be prevented. Therefore, variation in the relative dielectric constant due to ~~the~~

moisture contained in the porous insulating film 35 ^{is} ~~can~~
~~be~~ suppressed.

Furthermore, if ~~the~~ moisture is contained in the
 porous insulating film 35 ^{is formed} ~~from the beginning~~, the ~~out-flow~~
 5 ~~flowing out~~ of such moisture ^{at} ~~to the peripheral portions~~
 can be prevented and thus ~~the~~ corrosion of the lower
 wiring 33, etc. can be prevented.

~~Besides~~, the PE-CVD TMS SiO₂ film has ² ~~the quality~~
~~of the density~~ ^{that of a} that is equivalent to the silicon nitride
 10 film, but has ~~the quality of the~~ small relative dielectric
 constant, ~~that is largely different from the silicon~~
~~nitride film~~. Accordingly, if the PE-CVD TMS SiO₂ film
 is employed as the interlayer insulating film, the
 smaller relative dielectric constant can be maintained.
 15 In particular, if the PE-CVD TMS SiO₂ film is employed
 as the barrier insulating film and the protection film
 that ^{respectively} ~~protect~~ the upper and lower surfaces of the porous
 insulating film 35, the smaller relative dielectric
 constant can be maintained ^{for} ~~as~~ the ^{whole} ~~overall~~ interlayer
 20 insulating film ^{made up of} ~~containing~~ all of them.

In the above fifth embodiment, ^{an} ~~a~~ thermal oxide film
 formed by heating ~~it~~ ^{an} in the oxygen-containing atmosphere
 to oxidize the silicon substrate 31, an NSG film formed
 by the CVD method using ^{an} ~~the~~ organic silicon-containing
 25 gas, a BPSG film (BoroPhosphoSilicate Glass), etc. ~~may~~
~~be employed as~~ the underlying insulating film 32. ^{may be} But
 the PE-CVD TMS SiO₂ film which is formed by the plasma

CVD method according to the present invention may^{2/30} be employed.

~~Sixth Embodiment~~

FIGS. 14A to 14C are sectional views showing a semiconductor device and a method of manufacturing the same according to a sixth embodiment of the present invention.

FIG. 14C is a sectional view showing a semiconductor device according to a sixth embodiment of the present invention.

~~In this semiconductor device, a difference from the~~ *of this sixth embodiment differs*
~~fifth embodiment is~~ *in* that a side wall of the via hole 37 is covered with a PE-CVD TMS SiO₂ film 39a of the present invention and thus the porous insulating film 35 is not exposed from the inner surface of the via hole 37.

In this manner, if a sidewall protection layer 39a ~~made~~ *the structure shown in* of the PE-CVD TMS SiO₂ film is added to FIG. 13F, the porous insulating film 35 can be shielded almost ~~completely~~ *completely* from the ~~outside~~ *ambient atmosphere* by the PE-CVD TMS SiO₂ film according to the present invention. Therefore, the advantage ~~about the entering and discharging of the~~ *with regard to protection from* moisture explained in ~~the fifth embodiment can be~~ *connection with* enhanced ~~much more~~ *in further*.

In order to ~~implement~~ *form* the above structure, as shown in FIG. 14A, the PE-CVD TMS SiO₂ film 39 to which the present invention is applied is formed on the protection film 36 so as to cover the via hole 37 after the step

shown in FIG.13E. Then, as shown in FIG.14B, the PE-CVD TMS SiO₂ film 39 is etched by ~~the~~ anisotropic etching to leave the PE-CVD TMS SiO₂ film 39a on the sidewall of the via hole 37. Then, as shown in FIG.14C, the upper wiring 38 made of copper or aluminum is formed ^{and} ~~to be~~ connected to the lower wiring 33 via the conductive film.

^{above} ~~With the above,~~ ^{while} the present invention is explained in detail ^{with reference to various} ~~based on the~~ embodiments, ~~and~~ the scope of the present invention is not limited to ^{the} ~~examples~~ ^{of} ~~given~~ ⁱⁿ ~~concretely~~ in the above embodiments. Variations ^{made within} ~~of the~~ above embodiments may be ~~contained in~~ the scope of the present invention without departing from the gist ^{thereof.} ~~of the~~ present invention.

~~Other Embodiments~~

For example, as shown in FIG.15, the underlying insulating film 22 or 32 ^{is} ~~formed~~ only of the PE-CVD TMS SiO₂ film ^{and} ~~is~~ formed directly on the silicon substrate 21 or 31; ^{however, an} ~~but the~~ underlying insulating film 22 or 32 having ~~the~~ multi-layered structure consisting of double layers, ~~that are~~ formed by laminating the BPSG film or the thermal oxide film 61 and the PE-CVD TMS SiO₂ film 62 in sequence from the bottom, ^{utilized} ~~or more~~ may be formed. In this case, it is important to arrange the PE-CVD TMS SiO₂ film ^{at} ~~at~~ the uppermost layer.

Further, as shown in FIG.16, a single interlayer insulating film 63 ^{is} ~~interposed~~ between the lower wiring 33 and the upper wiring 65 ~~may be~~ formed on the substrate

20c. In this case, the interlayer insulating film 63 is made of the silicon-containing insulation film. Moreover, the lower wiring 33 and the upper wiring 65 may be connected via an opening ~~portion~~ 64 ^{penetrating} ~~formed to~~
 5 ~~perforate~~ the interlayer insulating film 63.

As described above, according to the present invention, the silicon-containing insulating film is formed on the substrate. In the silicon-containing insulating film according to the present invention, ^{the}
 10 ~~peak of the~~ ^{infrared} ~~absorption intensity of the infrared rays~~ is in a range of the wave number 2270 to 2350 cm⁻¹, ^{the} ~~a~~ film density is in a range of 2.25 to 2.40 g/cm³, and ^{the} ~~a~~ relative dielectric constant is in a range of 3.3 to 4.3.

The silicon-containing insulating film is formed
 15 by ~~plasma~~ ^{converting into a plasma, i.e.} ~~forming gas~~ ^{contains} ~~that consists of~~ ^{any one} selected from the group consisting of ~~the~~ alkoxy compound^s having Si-H bonds and ~~the~~ siloxane^s having Si-H bonds and ~~any one~~ ^{an} oxygen-containing gas selected from the group consisting of oxygen (O₂), nitrogen monoxide (N₂O), nitrogen dioxide (NO₂), carbon monoxide (CO),
 20 carbon dioxide (CO₂), and water (H₂O). ~~to react.~~ ^{It has been shown that}
 According ~~to~~ ^{the} experimentally [✓] the silicon-containing insulating film in the above range
 ~~for~~ ^{infrared} ~~of the peak of the absorption intensity of the infrared~~
 25 ~~rays~~ ^{for} and in the above range ~~of the~~ film density is dense, has ^a ~~the~~ small relative dielectric constant, and has ^{a low} ~~the~~ small amount of contained moisture in the film. ~~And that~~

~~film formed in the above manner is same.~~

Therefore, if the above silicon-containing insulating film is employed as the insulating film ~~to~~ cover ^{ing} wirings or as the barrier insulating film ~~to~~ sandwich ^{ing} the low dielectric constant insulating film that constitutes the interlayer insulating film interposed between the upper wiring and the lower wiring, the dielectric constant of the insulating film ~~to covering~~ ^{ing} the wirings or that of the overall interlayer insulating film can be lowered while preventing ~~the~~ corrosion of the wiring and ^{preventing} ~~the~~ increase in the leakage current.

ABSTRACT OF THE DISCLOSURE

The present invention relates to a film forming method of forming an interlayer insulating film having a low dielectric constant ^{for} to cover ^{ing} a wiring. ~~In~~ ^{The} construction, an insulating film ~~for~~ covering a wiring ^{is} ~~is~~ formed on the substrate by ^{converting into a plasma and reacting} ~~plasma~~ ^{including a component} ~~plasma~~ forming gas, ~~that consists of any one~~ ^{the} selected from a group consisting of alkoxy compound ^s having Si-H bonds and siloxane ^s having Si-H bonds and ⁱⁿ ~~any one~~ oxygen-containing gas selected from ^{the} a group consisting of O₂, N₂O, NO₂, CO, CO₂, and H₂O, ~~to react~~.